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Can agricultural trade improve total factor productivity? Empirical evidence from G20 countries

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Improving agricultural total factor productivity is essential to achieving the high-quality and sustainable development of agriculture. As major global agricultural producers, the G20 countries play an important role in agricultural product trade and development. As such, it is well-positioned to play a positive role in improving agricultural total factor productivity. This paper uses the DEA-Malmquist index method to measure agricultural total factor productivity (TFP) in G20 countries from 2010 to 2019, and analyzes the impact of agricultural trade on TFP using the two-way fixed effects model. It finds that (1) the main source of agricultural TFP growth in G20 countries is technical progress, while the effect of technical efficiency on agricultural TFP is not obvious. (2) Agricultural trade can significantly improve agricultural TFP growth in G20 countries, and the effect is more obvious in developed countries. From the perspective of trade flow, the positive effect of export trade on agricultural TFP is stronger. (3) The institutional environment strengthens the improvement effect of agricultural trade on agricultural TFP. Thus, this study not only provides valuable insight into the relationship between agricultural trade and agricultural productivity, but also offers a strong argument in favor of the formulation of relevant policies to improve agricultural productivity and promote a more sustainable agricultural sector.

KEYWORDS

agricultural trade, agricultural total factor productivity, trade flow, institutional environment, G20 countries

1. Introduction

In recent years, the increase in global extreme weather, natural disasters, environmental constraints such as land and water scarcity, and the growing global population have put tremendous pressure on agricultural production (Zhang et al., 2018; Cheng et al., 2022). At the same time, the international economic and political environment has become increasingly complex, with the rise of counter-globalization, the resurgence of trade protectionism, and the continued tightening of policies related to agricultural trade in various countries (Anderson, 2022). The increasingly strict control of the international agricultural market and the rising uncertainty of the trade environment have affected the supply, demand, and price stability of the food market while the balance pattern between food production and food trade is in crisis (Rutten et al., 2013). The supply and demand situation of agricultural products is increasingly tense, in which case the world faces the risk of declining food production capacity and lack of food security. The issue of food security has attracted the attention of many countries as early as the economic recession at the beginning of the 21st century (Naidanova and Polyanskaya, 2017). Many scholars have conducted studies on it.

Food security is a global issue that requires individual countries or international organizations to join forces to solve the problem. The Group of Twenty (G20) is a typical mechanism of informal dialogue, which includes 19 countries and one international organization. The G20 was established to cope with the possible impact of the Asian financial crisis, hoping to promote the reform of the international financial system through its meeting mechanism and to build a bridge between developed and developing countries for discussions and consultations on relevant substantive issues. With the increasing complexity of the global economic situation, the issues discussed by the G20 are no longer limited to the financial field but have gradually expanded to include almost all global economic governance issues, including trade, investment, agriculture, development, refugees, climate change, anti-corruption, etc., thus seeking cooperation and promoting the stability and sustained growth of the world economy through continuous consultations. Most of the countries involved have strong agricultural development capacity, and their food supply accounts for 80% of the total global supply, occupying a very important position in the global agricultural field. Agriculture is the foundation of the global food supply system (Prosekov and Ivanova, 2018), so the role of stable development of agriculture in G20 countries for global food security should not be underestimated.

The State of Agricultural Markets 2020 report published by the Food and Agriculture Organization of the United Nations argues that global trade is one of the cores of the development process that can drive inclusive economic growth and sustainable development and increase resilience to shocks. Agricultural trade, as one of the global trade sectors, can achieve the effective distribution of food resources through cross-border trade, which affects the supply, access, utilization and stability of food (Maasdorp, 1998; Kalimullina and Orlov, 2020). Economic history has shown that total factor productivity (TFP) is a key determinant of economic development and economic growth. It is important to note that GDP growth is not the same as economic growth; while GDP growth reflects an increase in the total value of goods and services produced in an economy, economic growth encompasses a much broader understanding of the health of an economy. There is a growing body of evidence that suggests that agricultural trade can have a impact on agricultural TFP. One study has found that trade liberalization in the agricultural sector led to an increase in agricultural TFP in African countries (Sunge and Ngepah, 2020). This suggests that developing agricultural trade may provide a benefit to agricultural TFP in different countries. Furthermore, the G20 countries are the world's largest economies and account for more than 75% of global trade and nearly 80% of world trade in agricultural products (Forward, 2019; G20 Agriculture Ministers' Meeting., 2019). This indicates that G20 countries have been major players in the global agricultural market.

Based on the above background, this study focuses on the impact of agricultural trade in G20 countries on their domestic agricultural TFP growth. Firstly, by reviewing the literature in related fields, an understanding of the existing research conclusions on agricultural trade and agricultural total factor productivity can be gained, and this study can provide theoretical support for the hypotheses. Secondly, the DEA-Malmquist index method is used to measure the agricultural TFP index of G20 countries from 2010 to 2019 while a two-way fixed effects model is constructed to explore the role of agricultural trade on agricultural TFP. Thirdly, this study further divides agricultural trade into import trade and export trade to analyze the different effects of a range of trade flows. Finally, this study uses the institutional environment as a mediating variable to discuss the moderating role of institutional environment in the relationship between agricultural trade and agricultural TFP. This study makes a marginal contribution in three aspects. Firstly, although there have been numerous studies on the factors affecting the growth of agricultural TFP, there are relatively few which focus on agricultural trade. This study examines the impact of trade in agricultural products on agricultural TFP, supplementing research in related fields on factors that affect agricultural TFP. Secondly, the majority of the relevant literature is based on research focused on a single country. For example, Chinese scholars mainly analyze agricultural TFP at the provincial level, and there is a lack of literature on horizontal comparison between countries based on an international perspective. This study measures the agricultural TFP of 19 G20 countries, supplementing research from a more macro international level perspective. Finally, there is some literature that introduces the concept of institutional environment into the analytical framework of agricultural trade and agricultural TFP, stressing that the moderating role played by the institutional environment is not yet clear. By taking the institutional environment as a factor regulating agricultural product trade and agricultural TFP, this study broadens the scope of the institutional environment and further deepens the understanding of the relationship between agricultural product trade and agricultural TFP. This study aims to make suggestions for the development of agriculture and agricultural trade in G20 countries by studying agriculture and agricultural trade in G20 countries while also comparing the current level of development of China's agriculture from an international perspective to provide a reasonable basis for promoting the high-quality transformation of its agriculture.

2. Literature review

After the concept of total factor productivity was put forward, the initial academic research mainly used different methods to measure the TFP of various industries and explore the quality of economic growth in various industries. After testing many scholars have agreed that there are four main methods for calculating TFP in agriculture: production function method, index method, data envelopment analysis (DEA), and stochastic frontier analysis (SFA). At present, scholars mainly utilize DEA and its related methods for research. DEA is a linear programming method that uses a set of input and output elements to determine the production frontier and then maps the actual production and input-output to the production frontier to measure the TFP index. In addition, scholars at home and abroad mostly combine the data envelopment and index methods when calculating agricultural TFP. Zhou (2009) calculated China's agricultural TFP based on the DEA-Malmquist empirical method, and broke it down it into multiple indicators. They concluded that the growth of China's agricultural TFP has regional imbalances while there are differences in the contributions of technological progress and technological efficiency. Che and Yang (2010) used this method to draw the conclusion based on the international comparison that, when faced with the same land problem, the growth of agricultural TFP in developed countries is faster than that in developing countries.

With the increasingly complex development of the global economy, only measuring agricultural TFP can no longer meet the need to explore the direction of agricultural development. Therefore, scholars use econometric empirical models to analyze the impact

mechanisms of the main factors on agricultural TFP and explore many elements that affect the growth of agricultural TFP. The relevant literature mainly focuses on the following four aspects.

From the perspective of factors related to agricultural production, Zheng and Gao (2021) believe that agricultural mechanization and rural labor transfer have significantly promoted the growth of agricultural TFP, however agricultural mechanization has a lagging effect. Yang et al. (2019) concluded from the perspective of spatial measurement that rural infrastructure has positive spillover effects on agricultural TFP in the region and adjacent regions. Bagherzadeh (2012) determined that agricultural R&D positively influences agricultural TFP when studying agricultural TFP in Iran. Chandio et al. (2022a) conducted research on seven Asian nations and ascertained that information and communication technology (ICT) has a beneficial effect on agricultural production, and that the advancement of agricultural technology can have a similar effect on the quality of agricultural production.

In terms of climate change factors, Guo et al. (2022) carried out a study on 43 countries and determined that, if the influence of climate factors is taken into account, it will be detrimental to these countries' levels of agricultural productivity. Sheng et al. (2021) compared the agricultural TFP of the Broadacre farm in Australia based on meteorological shocks. They conclude that meteorological shocks initially deviate agricultural TFP and then converge toward a long-run equilibrium. That is to say, farmers in areas with harsher weather conditions can adapt to weather shocks faster, while policies that reduce adaptation and adjustment costs will help make up for losses under weather shocks. Chandio et al. (2022b) contend that greenhouse gas emissions will have long-term consequences on agricultural productivity in SAARC countries, especially methane (CH_4) and nitrous oxide (N_2O), which have a detrimental impact on agricultural output. Chandio et al. (2022c) determined that rises in carbon dioxide (CO_2) emissions and average temperature are not beneficial to agricultural development in ASEAN.

At the system and policy levels, McMillan et al. (1989) believed that the change of agricultural production system is the root cause of the growth of agricultural TFP. However, Lambert and Parker (1998) believed that with the improvement of economic development level, the effect of production system on agricultural productivity will continue to weaken. Bojnec and Latruffe (2013) examine the link between farm size, subsidies and performance in Slovenia between 2004 and 2006. In Slovenia, pre- and post-access farm performance, as measured by technical efficiency, was positively correlated with farm size, while the persistence of small farms may be related to the provision of generous subsidies and this is negatively related to the technical efficiency of farms but positively related to their profitability. Latruffe et al. (2008) analyzed the impact of public subsidies on farm efficiency in Hungary, the Czech Republic and Slovenia, and Romania before and after EU accession. The study found that subsidies negatively affected the agrotechnical efficiency of the crop sector in Hungary 2001–2005, Czech dairy firms 2000–2004, Slovenia 1994–2003, and Romania in 2005.

Current academic research on trade and TFP has focused on industry or manufacturing with relatively little research on agriculture. Abizadeh and Pandey (2009) investigated whether trade openness had different effects on TFP growth in three major sectors of a given economy. While confirming the positive effect of openness on TFP growth in the total economy, openness had no significant effect on TFP growth in the agriculture and industrial sectors. Yoo et al. (2012) studied the sources of agricultural TFP in Korea based on agricultural trade openness, agricultural R&D and extension, and found that trade openness significantly increased agricultural TFP in Korea. Fleming and Abler (2013) analyzed the relationship between trade and agricultural productivity in Chile, a middle-income country, and found that importing goods and spillover effects of export commodities increase the productivity of traditional crops. Aldieri et al. (2021) find that agricultural trade generates significant technology spillover effects but is not the root cause of agricultural TFP growth in each country, while the role of technology spillover effects varies depending on the differences in agricultural resource endowments. In terms of trade structure, there is a more significant spillover effect of trade in agricultural intermediate goods relative to trade in agricultural products and agricultural capital goods. Levin and Raut (1997) studied the export effects of primary and manufactured goods and concluded that manufactured goods exports positively contribute to economic growth, while primary exports have a negative impact on economic growth. Using rural human capital as a threshold variable, Sheng et al. (2021) found differences in the effects of agricultural exports and imports on TFP generation, with a significant double threshold effect of imports on agricultural TFP growth and a single threshold effect of exports on agricultural TFP growth. Wang et al. (2020) concluded that an increase in both import and export trade can increase the level of agricultural TFP. However, the growth of GDP per capita will weaken the effect of agricultural trade on the increase of agricultural TFP while the increase of export trade has a more significant effect on the increase of agricultural TFP level. In a study on China's agricultural cooperation with the Belt and Road, Zhou and Tong (2022) found that bilateral trade can increase agricultural productivity. Herrendorf and Teixeira (2005) argue that binding quotas lead to the use of inefficient technologies in import-competing industries and that limited quotas or tariffs mean that the production of import-competing industries is greater than the effective quantity. In that case, international trade barriers reduce TFP.

In addition, with the rising concern regarding the development of a green economy, some scholars have conducted studies on agricultural trade and agricultural green TFP to provide theoretical support for the sustainable development of agricultural trade while giving full play to its positive impact on agricultural green TFP (Seppelt et al., 2020; Liu et al., 2022; Song et al., 2022).

The existing literature on institutional environmental factors has mainly focused on topics such as manufacturing upgrading (Amoako et al., 2022), enterprise innovation (Bjerke and Johansson, 2022), foreign direct investment (Rashid and Razak, 2016), and foreign trade location choice (Pellegrina, 2022), while relatively few studies have been conducted on the impact of agricultural trade. Hu et al. (2021) argue that China prefers host countries with a sound institutional environment when exporting agricultural products to countries along the Belt and Road, but the preference for different dimensions of institutional environment varies. Liu and Wang (2017) study agricultural trade from the economic dimension of the institutional environment and conclude that a good economic environment is conducive to improving the efficiency of agricultural trade in countries along the Belt and Road. At the same time, scholars' research on the influence of institutional environment on TFP is mainly focused on enterprise TFP growth

and industrial TFP with the research on agricultural TFP being relatively vacant.

By reviewing the literature in related fields, we can find that the current research on agricultural total factor productivity has the following characteristics. (1) Since the development of the economy is influenced by many factors, the measurement of agricultural TFP alone can no longer support the research for exploring the quality development of agriculture. Therefore, domestic and foreign experts and scholars, based on the measurement of agricultural TFP, again conducted regression analysis of the influencing factors. There has been a lot of research on the factors influencing agricultural TFP growth but, in general, there are few studies adopting the agricultural trade perspective. Most of the studies on the influence mechanism between the two are focused on the technical progress index and technical efficiency index disaggregated from total factor productivity, human capital, and technological spillover, and there is a lack of studies on the moderating role of institutional environment. (2) Most of the relevant literature is based on the study of individual countries, for example, Chinese scholars mainly study agricultural TFP at the provincial level, and there is no literature on cross-sectional comparison between countries based on international perspective, so it is difficult to see a specific situation, namely the agricultural development of a country set in a larger comparison. (3) There is a paucity of literature that introduces the concept of institutional environment into the analytical framework of agricultural trade and agricultural TFP, thus the moderating role played by the institutional environment in it is unclear. To sum up, this study will use the DEA-Malmquist index method to measure agricultural TFP in G20 countries. On this basis, conduct regression analysis on agricultural trade and agricultural TFP in G20 countries based on international perspective better explores the relationship between them and there is a further discussion of the moderating role of institutional environment in order to enrich the relevant theoretical and empirical studies.

3. Research hypothesis

In the field of international trade, endogenous growth theory suggests that international trade leads to "spillover effects" and promotes knowledge spillover, i.e., international trade activities increase the total volume of global trade while facilitating advanced technology, knowledge and human capital, which promotes the flow of these advanced factors around the world and accelerates the domestic accumulation rate of the trading country itself. Arrow (1971) proposed the "learning-by-doing" effect, which refers to the accumulation of experience in the production process that leads to labor productivity gains and technological spillovers, i.e., other producers can also learn the "learning by doing" effect, which refers to the increase in labor productivity and technological spillover caused by the accumulation of experience in the production process, i.e., other producers can also improve productivity by learning. Romer (1990) argues that the domestic and international markets respectively do not have the same impact on economic growth, and even if there is already a large domestic market, participation in international market transactions can still can increase the economic growth rate. Moreover, international trade can, to a certain extent, reduce domestic R&D input costs and indirectly affect domestic capital accumulation because knowledge diffusion and human capital have external effects, thus increasing the economic development rate of each country. Läpple et al. (2016) argued from the perspective of knowledge spillover that agricultural trade knowledge would have a first spillover effect on agricultural TFP in the importing location, followed by a secondary spillover effect of tacit knowledge on agricultural TFP in neighboring regions, while the secondary spillover effect is higher than the first spillover effect.

Further analysis, due to the different trade flows, the impact of agricultural imports and exports on agricultural TFP may be somewhat different. From the perspective of import trade, on the one hand this may lead to the emergence of import competition, which will impact on the price of the domestic market, depress the price of agricultural products, reduce domestic agricultural production and cause a negative impact on domestic agricultural production (Berger et al., 2021). On the other hand, import competition caused by import trade will also force domestic agricultural production to improve production technology, increasing investment in research and development, and update agricultural machinery and equipment. At the same time, the technology spillover from international trade (Li, 2009), the import process will carry advanced technology. The technology difference between different regions makes the production technology flow from relatively high regions to relatively low regions. Domestic agricultural producers can absorb the advanced technology introduced by imported agricultural products, promoting the improvement of industrial production technology level, and then promote the improvement of domestic agricultural TFP level. Hong et al. (2010) argues that whether it is domestic independent innovation or foreign technology introduction, agricultural import trade mainly promotes TFP through the technology spillover effect.

From the perspective of export trade, in the process of foreign exports, agricultural trade will intensify market competition, while agricultural exports must adapt to domestic and foreign market demand in order to achieve competitive advantage (Long, 2021; Mamba and Ali, 2022). Agricultural exports also promote the adjustment and upgrading of trade and industrial structures (Sun and Li, 2018), making the industrial structure more rational and thus promoting the improvement of agricultural TFP. At the same time, export trade opens up international markets and gives producers the opportunity to achieve economies of scale, while the expansion of markets promotes the improvement of technology level. However, the effect of export trade on agricultural TFP is not entirely positive. For example, the increase in production scale may make producers reluctant to introduce further innovation inputs (Venkataraman et al., 2019) and the sloppy export approach may also hinder the improvement of TFP (Stræte et al., 2022). Based on the above analysis, this study proposes hypothesis 1.

Hypothesis 1: The impact of agricultural trade on agricultural TFP is positively significant, but there are differences in the role of import and export trade respectively.

As mentioned above, agricultural trade has a facilitating effect on agricultural TFP to a certain extent, however the link between the two needs to be judged in conjunction with the institutional environment to reach a clearer conclusion. Trade activities require the existence of potential benefits on the one hand and the realization of economic benefits on the other (Porteous, 2022). The uncertainty of the market brings many risks to the transaction and increases the tangible or intangible trade costs. The risks and costs faced by international trade are often greater than those of domestic trade, so good

institutions are needed for restraint. The institutional environment can strengthen the role of agricultural trade in promoting agricultural TFP through the following ways. First of all, the institutional environment is there to regulate social actors and produce binding rules. A perfect institutional system can often shape a good business environment, laterally proving the reliability of trade partners and reduces the cost of finding trade objects before trade, while a good institutional environment can also provide protection for contract performance after trade and reduce economic risks. Overall, an effective institutional environment will reduce the uncertainty of trade, lower the transaction costs of international trade, and increase the incentive to trade, thus strengthening the technology spillover of agricultural trade. Second, international trade attracts and utilizes human capital and mobile resources on a global scale, while a well-developed system can promote the long-term accumulation of human capital and factors. Therefore, a good institutional environment not only promotes the combination of internal and external factors but also improves the efficiency of factor resource allocation and accelerates capital accumulation, which in turn increases the rate of TFP growth. Third, technological innovation is one of the important influencing mechanisms of agricultural trade on agricultural TFP growth. While technological innovation has become the main source of economic growth in various countries, technological competition and embargoes are becoming increasingly severe globally (Chi, 2022). In this context, a good institutional environment becomes an important foundation for technological innovation, such as a reasonable government performance indicator system stimulating the development of technological innovation while a legal system can protect intellectual property rights after technological innovations. Based on the above analysis, this study proposes hypothesis 2.

Hypothesis 2: The institutional environment has a significant positive moderating effect on the relationship between agricultural trade and agricultural total factor productivity.

4. Models, data and variables

4.1. Models

The purpose of this study is to examine the effect of agricultural trade on agricultural TFP in G20 countries. Therefore, agricultural total factor productivity (TFP) in G20 countries is selected as the dependent variable and trade in agricultural products (trade) is the core independent variable.

To eliminate the possible effects caused by heteroskedasticity, the natural logarithm of the explanatory variables and the core explanatory variables are taken in the regression model. x denotes a series of control variables. Including foreign direct investment, human capital, urbanization level, economic development level, irrigation infrastructure, and agricultural employment size, some of which are taken as natural logarithms according to the individual variables, i denotes region, t denotes time, μ_i denotes year fixed effects, λ_t denotes individual fixed effects, and ε_{it} denotes random error term to indicate the omitted variables in the model or and the effect of statistical errors on the explained variables. With reference to the methods used in existing studies, the baseline econometric model for this study is set as follows:

$$lntfp_{it} = \alpha + \beta lntrade_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

This study divides agricultural trade into import and export trade respectively, and includes both in the same econometric model as the core explanatory variables in order to examine the impact of different trade flows of agricultural trade on agricultural TFP. We compare the coefficient results obtained with reference to the baseline regression analysis and the econometric model is set as follows:

$$lntfp_{it} = \alpha + \beta_0 lnimport_{it} + \beta_1 lnimport_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

In order to further investigate the moderating role of institutional environment in the relationship between agricultural trade and agricultural TFP growth, this study incorporates institutional environment as a moderating variable in the econometric model and generates an interaction term between agricultural trade volume and institutional environment. In order to eliminate possible multicollinearity effects between variables, the indicators of agricultural trade volume and institutional environment are centrally transformed separately with reference to the existing literature. Based on the above, the moderating effect model is constructed as follows:

$$lntfp_{it} = \alpha + \beta lntrade + \beta_1 inst + \beta_2 lntrade^{*} inst + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

4.2. Variables

Regarding total factor productivity (tfp) in agriculture, the previous paper measured agricultural TFP in G20 member countries using DEAP2.1 software based on the DEA-Malmquist index method. The agricultural TFP growth index in the base period (2009) was made to be 1, and the TFP indices for each year were multiplied to obtain the cumulative form of TFP for the year.

This study selects agricultural production input indicators and output indicators, and chooses the added value of agriculture, forestry, animal husbandry and fishery as the output indicator. Removing the "intermediate consumption" from the total agricultural output value allows for a more accurate reflection of the agricultural output. The input factor index used includes land, agricultural labor, chemical fertilizer, and agricultural machinery inputs respectively as well as irrigated farmland area. Land input is shown by the area of agricultural land, which includes land for annual crops, land for perennial crops including orchards, vineyards, and pastures. Agricultural labor input is calculated by the total number of agricultural employees in the area where the main economic activity is agriculture; this indicator reflects the actual utilization of agricultural labor at different times. Agricultural machinery input is represented by the total metric horsepower (CV) of the main agricultural equipment in use, which includes the number of four-wheel passenger tractors, two-wheel walk tractors, power harvester-threshers, and milking machines. Fertilizer input is calculated as the pure conversion of inorganic nitrogen, phosphorus, potassium, and organic nitrogen fertilizers. The irrigated area is measured by the actual effective irrigated area, taking into account the productivity difference between irrigated and rain-fed farmland, thereby demonstrating how changes in agricultural land area affect output growth over time.

This study uses the DEA-Malmquist index method to measure the agricultural TFP of the G20 countries. The output-oriented

Malmquist index formula is as follows:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = [\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \times \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}]^{\frac{1}{2}} \quad (4)$$

Formula (4) can be further adjusted as:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}[\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \times \frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}]^{\frac{1}{2}} \quad (5)$$

Formula (5) can be decomposed into:

$$EC = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}, \quad TC = [\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \times \frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}] \quad (6)$$

In formula (5), (x^t, y^t) stands for the input and output vectors of period t, and (x^{t+1}, y^{t+1}) stands for the input and output vectors of period t+1. Using the technological frontier in period t as a numerical reference, D_0^t and D_0^{t+1} represent the distance between the DMU in the base period and the next period, with $D_0^t(x^t, y^t)$ being the distance function of period t, and $D_0^{t+1}(x^{t+1}, y^{t+1})$ being the distance function of period t+1. M_0 is the Malmquist index indicating the change in productivity; when $M_0 > 1$, the total factor productivity increases; when $M_0 < 1$, it signifies a decrease in total factor productivity; and when $M_0 = 1$, it implies that the total factor productivity has remained the same. After decomposing total factor productivity, total factor productivity (TFP) = technical efficiency (EC) × technological progress (TC), with technical efficiency (EC) = pure technical efficiency (PE) × scale efficiency (SE).

Agricultural trade volume (trade), the sum of agricultural import trade volume and export trade volume of country i in year t is selected to measure the level of national agricultural trade. Agricultural trade is divided into import and export trade respectively and discussed separately. Regarding agricultural import trade volume (import), the agricultural import trade volume of country i in year t to measure the national level of agricultural import trade. In terms of Agricultural export trade (export), agricultural export trade of country i in year t measures the level of national agricultural export trade.

Control variables are as bellows. Foreign direct investment (fdi), the net inflow of foreign direct investment as a proportion of GDP, is chosen to measure the net inflow of foreign direct investment in agriculture and, since the impact path of foreign direct investment on agriculture may come from multiple industries, industry-wide net FDI inflow data is chosen. Human capital (edu), influences the production behavior and livelihood choices of farm households. Years of education and educational inputs are often used to represent human capital variables in the existing literature. Given the availability of data for G20 countries, the share of education expenditure in gross national income (GNI) of each country is used in this study (Busemeyer, 2007; Garritzmann and Seng, 2016). Level of urbanization (urb) is expressed as the ratio of urban population to total population. Changes in the level of urbanization will, on the one hand, promote the diffusion of technology and improve agricultural production techniques. On the other hand, it will lead to a shift of labor from the agricultural to the non-agricultural sector and reduce the input of farm households in agriculture. Economic development level (gdp) – i.e., GDP per capita – is chosen in order to better measure the impact of a country's economic development base on agricultural TFP. Countries with a high level of economic development tend to pay more attention to scientific and technological research and development, thus promoting the growth of agricultural TFP. However, agriculture is not necessarily the dominant industry in these countries, and less investment in agricultural development may also have a negative effect on agricultural TFP. Irrigation infrastructure (irr), using the proportion of effective irrigated agricultural area to the cultivated area, can better reflect the quality condition of land used for cultivation as well as the level of irrigation infrastructure in G20 countries, which has a direct impact on agricultural TFP. Agricultural employment size (labor), expressed as the share of agricultural employment in total employment, the number of labors in the agricultural production process of agricultural employment has a certain degree of influence on agricultural TFP.

As for institutional environment (inst), the World Governance Indicator (WGI) is selected to measure the level of institutional environment. The WGI includes six indicators, including voice and responsibility, political stability, government efficiency, regulatory quality, level of the rule of law, and corruption control, while the value of each indicator ranges from −2.5 to 2.5, with higher scores indicating a more perfect institutional environment. Because of the complexity of the institutional factors that have an impact on this study, the average of the six indicators is chosen in this chapter as the national institutional environment indicator to make the meaning expressed by the variables more comprehensive. Table 1 shows the description of dependent and independent variables.

TABLE 1 Description of dependent and independent variables.

Indicators	Variable name	Calculation method
tfp	Total factor productivity	DEA-Malmquist index, using cumulative form
trade	Agricultural trade volume	The sum of import and export of agricultural products trade
import	Agricultural trade imports	Total import value of agricultural products
export	Agricultural trade exports	Total export value of agricultural products
fdi	Foreign direct investment	Foreign direct investment/GDP
edu	Human capital	Education spending/GNI
urb	Urbanization level	Urban population/total population
gdp	Economic development level	GDP per capita by country
irr	Irrigation infrastructure	Effective irrigated area/cultivated land area
labor	Size of agricultural employment	Employed persons in agriculture/total employment
inst	Institutional environment	Average of six WGI indicators

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TABLE 2 Agricultural TFP of G20 countries from 2010 to 2019.

Nation	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Argentina	1.356	1.288	1.131	1.265	1.283	1.398	1.322	1.359	1.165	1.414
Australia	0.948	1.027	1.037	1.034	0.989	1.033	0.953	1.016	1.004	0.894
Brazil	1.028	1.047	0.977	1.016	1.000	1.005	0.933	1.044	1.031	1.010
Canada	1.035	1.067	1.073	1.235	1.168	1.243	1.166	1.324	1.352	1.407
China	0.994	0.993	0.998	1.025	1.100	1.087	1.206	1.304	1.403	1.406
France	0.948	0.999	0.908	0.862	1.027	1.064	0.898	1.021	1.090	1.060
Germany	0.852	0.817	0.858	0.905	0.995	0.871	0.884	0.956	0.807	0.926
India	1.053	1.097	1.101	1.139	1.112	1.084	1.122	1.162	1.167	1.183
Indonesia	1.007	1.042	1.063	1.027	1.049	1.081	1.105	1.101	1.127	1.207
Italy	1.011	1.045	1.017	1.049	1.022	1.050	1.026	0.994	1.034	0.991
Japan	0.932	0.993	0.965	0.945	0.923	0.943	0.849	0.843	0.807	0.828
South Korea	0.966	0.982	0.976	0.886	0.944	0.963	0.928	0.950	0.945	1.130
Mexico	1.022	0.984	1.050	1.082	1.126	1.146	1.192	1.267	1.305	1.317
Russia	0.897	1.039	1.041	1.100	1.135	1.168	1.189	1.221	1.243	1.287
Saudi Arabia	1.077	1.038	1.043	1.076	1.013	0.951	1.008	1.115	1.229	1.255
South Africa	0.996	0.983	0.962	0.998	1.100	1.007	0.951	1.131	1.132	1.059
Turkey	1.067	1.118	1.112	1.084	1.132	1.228	1.015	1.100	1.289	1.267
U.K.	1.229	1.506	1.248	1.252	1.596	1.347	1.126	1.128	0.987	1.145
United States	0.948	0.880	0.863	1.013	1.006	1.035	1.092	1.065	1.139	1.192

Data source: Calculated using DEAP2.1 software and related indicators.

TABLE 3 Descriptive statistics of variables.

Variable name	Unit	Mean	Standard	Min	Max
Total factor productivity (tfp)		1.076	0.140	0.807	1.506
Agricultural trade volume (trade)	Billions of dollars	978.765	772.058	171.425	3,458.853
Agricultural trade imports (import)	Billions of dollars	507.933	466.628	22.051	1,945.021
Agricultural trade exports (export)	Billions of dollars	470.494	382.415	35.763	1,757.485
Foreign direct investment (fdi)	%	1.940	1.144	0.002	5.534
Human capital (edu)	%	4.480	1.237	1.790	7.186
Urbanization level (urb)	%	74.830	14.377	31.276	91.870
Economic development level (gdp)	USD	24,482.830	17,784.640	1,292.821	59,821.590
Irrigation infrastructure (irr)	%	25.916	20.330	1.591	61.869
Size of agricultural employment (labor)	%	10.270	12.735	0.060	49.260
Institutional environment (inst)		0.453	0.805	−0.749	1.675

4.3. Data

This study collected agricultural-related data from G20 member countries from 2009 to 2019, as the EU is an economic union and several of its main countries have already been included in the G20 member countries. The agricultural output indicators used for calculating the agricultural TFP value-added data of agriculture, forestry, animal husbandry and fishery were obtained from the WDI database of the World Bank; the Agricultural Productivity Database (International Agricultural Productivity); the United Nations Food and Agriculture Organization Database (FAOSTAT); the International Labor Organization Database (ILOSTAT); and the European Union Database (EUROSTAT).

The data source of agricultural products import and export trade volumes is from the UN COMTRADE database, the products in category 0, 1, 2 and 4 of SITC Rev.3 are selected, and the products in chapters 27 and 28 in category 2 are excluded by product attributes and summed up. The effective irrigated area and arable land area are taken from the UN Food and Agriculture Organization database (FAOSTAT). The world Governance indicators are obtained from the World Bank WGI database. The proportion of education input, GDP per capita, the proportion of agricultural employees, the proportion

of urbanization, and the proportion of foreign direct investment are obtained from the World Bank WDI database, and individual missing data are filled in by the interpolation method, which is the typical method used in academia. All the variables are treated with 1% tailing to control the possible effects of extreme values.

The detailed measurement results of the agricultural TFP are shown in Table 2. Parts of the DEA-Malmquist index >1 indicate a percentage point increase compared to the previous year, while parts <1 indicate a percentage point decrease. By using this method, we can observe the changes in the G20 agricultural TFP index and its decomposition indicators. From the detailed data, the agricultural TFP of Argentina, India, Indonesia, Mexico, Saudi Arabia, and the United Kingdom has been consistently >1 from 2010 to 2019, indicating a steady growth trend, while Germany, Japan, and South Korea have experienced a steady decline. The agricultural TFP indexes of China, France, Russia, South Africa, and the United States all showed a trend of first falling and then rising, with almost all of them declining year by year before 2013 or 2014, but beginning to grow rapidly after 2014. Moreover, Australia's agricultural TFP index fluctuates between rising and falling trends, with considerable fluctuations.

From the descriptive statistics in Table 3, it can be seen that the minimum value of TFP is 0.807, the maximum value is 1.506, the average value is 1.076, and the standard error is 0.14. This indicates that the TFP of G20 countries is relatively high, with some variation but not a substantial one. This could be due to the fact that these countries are already well-developed countries in the world, and so they all have relatively high TFP. The minimum value of trade is 171.425, the maximum value is 3,458.853, the average value is 978.765, and the standard error is 772.058, which showcases the large differences in the trade volume among G20 countries. This could be due to the varying degrees to which these countries depend on trade between the G20 countries.

5. Empirical analysis

Table 4 shows the results of a linear estimation of the impact of agricultural trade on agricultural TFP under the two-way fixed effects model. As can be seen from the results, the coefficient of the core explanatory variable agricultural trade volume is 0.277 after controlling for a series of relevant variables, which is positively significant at the 1% level of significance, i.e., for every 1% increase in agricultural trade volume, agricultural TFP will increase by 0.277%. This indicates that agricultural trade has a strong positive contribution to agricultural TFP growth, which is in line with the conclusion of Sunge and Ngepah (2020). Combined with the analysis of the theoretical basis, the increase of agricultural trade means, to a certain extent, the increase of agricultural openness to the outside world. Furthermore, the international trade of agricultural products is conducive to the full flow of resource factors, which brings about a technology spillover effect. Meanwhile, the "dry school" effect of international trade accelerates the capital accumulation of trading countries, thus promoting the growth of agricultural TFP (Hong et al., 2010; Läpple et al., 2016). At the same time, the "dry learning" effect of international trade accelerates capital accumulation in trading countries, thus promoting the growth of agricultural TFP (Arrow, 1971).

TABLE 4 Estimation results of the impact of agricultural trade on TFP.

	(1)	(2)
	lntfp	lntfp
lntotal	0.308***	0.277***
	(3.55)	(2.88)
fdi		−0.021***
		(−2.92)
edu		−0.064**
		(−2.15)
urb		0.008
		(0.87)
lngdp		−0.226
		(−1.45)
irr		−0.003***
		(−3.34)
Labor		−0.016*
		(−1.89)
Constant	−1.962***	0.411
	(−3.52)	(0.26)
Time fixed effects	Yes	Yes
Individual fixed effects	Yes	Yes
R-squared	0.275	0.390
Observations	190	190

*, **, ***Indicate significant at 10, 5, and 1% significance level respectively, t-statistic in ().

TABLE 5 Robustness tests.

	(1)	(2)	(3)
lntotal	0.230**	0.194**	0.282***
	(2.60)	(2.13)	(2.78)
Constant	−0.564	1.449	0.455
	(−0.33)	(0.80)	(0.27)
Control variables	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes
R^2	0.415	0.369	0.314
Observations	190	152	190

**, ***Indicate significant at 10 and 5% significance level respectively, t-statistic in ().

Among the control variables, FDI is negatively significant at the 1% level with a coefficient of −0.021, indicating that the net inflow of FDI fails to promote the growth of agricultural TFP, which on the one hand may be due to the fact that the proportion of net inflow of FDI to GDP used in this study is the total level of the whole industry, which may invest more in other industries and squeeze the development of agriculture; on the other hand, it may be due to the fact that Human Capital is negatively significant at the 5% level with a coefficient of −0.064, probably because after the increase in education investment improves the quality of the labor force, the latter is transferred

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TABLE 6 Endogeneity test.

	(1)	(2)
	FE	2SLS
l.lntotal	0.197*	
	(1.86)	
		0.370**
lntotal		(2.08)
Constant	0.739	0.662
	(0.41)	(0.41)
Control variables	Yes	Yes
Time fixed effects	Yes	Yes
Individual fixed effects	Yes	Yes
R-squared	0.340	0.755
Phase I F-value		69.950
Observations	171	171

*, **Indicate significant at 10 and 5% significance level respectively, t-statistic in ().

TABLE 7 Estimation results of the effects of agricultural imports and exports on TFP.

	(1)	(2)	(3)
	Import	Export	lntfp
lnimport	−0.052		−0.02
	(−0.87)		(−0.35)
lnexport		0.239***	0.235***
		(3.61)	(3.5)
Constant	0.457	−0.626	−0.602
	(0.28)	(−0.39)	(−0.37)
Control variables	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes
R-squared	0.360	0.407	0.407
Observations	190	190	190

***Indicate significant at 1% significance level respectively, t-statistic in ().

from the agricultural to the non-agricultural sector, which reduces the household's input in agricultural production, thus leading to a decrease in agricultural TFP. Irrigation infrastructure is negatively significant at the 1% level with a coefficient of −0.003, probably because irrigation infrastructure is a quasi-public good and is prone to "overuse" and "crowding effect" in farmers' production processes, which affects the increase of agricultural TFP. The size of agricultural employment is negatively significant at the 10% level, probably because there is too much labor in agricultural production, which in turn hinders the increase of agricultural productivity. There is a positive effect of the level of urbanization and a negative effect of the level of economic development with agricultural TFP, but neither is significant.

To ensure the objectivity and accuracy of the study, it referred to the previous literature and chose three more reasonable ways to conduct robustness tests which is shown in Table 5. Firstly, by shrinking the data before and after 3%, the test results of model (1) show that the significance and the direction of influence of the core explanatory variable agricultural trade volumes are basically consistent with the results of the benchmark regression, except for the change in the significance of individual control variables. Secondly, this study adjusted the sample period by screening out the data after 2017, while the results of model (2) show that the coefficients of the core explanatory variables become slightly smaller but their significance and direction of influence remain unchanged. In addition, this study re-measured the agricultural TFP index of G20 countries and added agricultural draft animal inputs to the input variables; the results of model (3) showed that the significance and direction of influence of the core explanatory variables did not change. Taking the three robustness tests together, it can be concluded that the econometric results of the baseline regressions in this study are basically robust and the core conclusions still hold.

In the related literature, some scholars believe that there may be a causal relationship between agricultural trade and agricultural TFP, i.e., agricultural trade affects agricultural TFP, but at the same time, agricultural TFP also affects agricultural trade, a situation that may lead to the endogeneity problem. In order to solve this issue, this study refers to the treatment of the endogeneity problem in existing studies. The agricultural trade volume with one period lag is both related to the agricultural trade volume in the current period and not affected by the agricultural TFP in the current period, so it is reasonable to use the agricultural trade volume with one period lag for the endogeneity test. First, the lagged agricultural trade volume in one period is used as the core explanatory variable for fixed effects estimation, and the results are shown in (1), where the coefficient of agricultural trade volume in one period is positively significant and consistent with the benchmark regression. Second, the agricultural trade volume in one lagged period is taken as the instrumental variable and the latter is estimated using the two-stage least squares method 2SLS. In the one-stage regression, the agricultural trade volume is positively significant with the instrumental variable at the 1% level, indicating that the instrumental variable is correlated with the endogenous variable while the one-stage F-value is 69.950, which is >10, indicating that there is no weak instrumental variable. The estimated results of model (2) show that the coefficient of the core explanatory variable agricultural trade volume is still positively significant. Thus, it can be concluded that the mutual causality endogeneity issue has a weak effect on the results of this study and the core findings of this study are valid. The result is shown in Table 6.

6. Further analysis

In order to verify the effect of agricultural trade on agricultural TFP growth whereby trade flow is more pronounced, this study divides the core explanatory variable, agricultural trade, into agricultural import trade and agricultural export trade. Model (3) in Table 7 incorporates the agricultural import and export trade volumes into the same econometric model to discuss the different effects they generate.

From the empirical results, the coefficient of agricultural import trade is negative and insignificant while export trade is significant at the 1% level with a coefficient of 0.235. Therefore, it can be assumed that the agricultural exports of G20 countries play a major role in

promoting the growth of agricultural TFP. Analyzing the theoretical basis, this may be due to the fact that the import competition brought about by the import trade suppresses the incentive of domestic agricultural producers, while the import trade required to meet the domestic market demand affects the innovation and R&D capacity of domestic agricultural development, so the role of agricultural import trade on agricultural TFP in G20 countries is insignificant and negative (Berger et al., 2021). In contrast, export trade does not only obtain direct economic benefits and increase investment in agricultural technology R&D, but also triggers domestic agricultural producers to improve production methods and adjust production scale through indirect "learning effect" and "scale benefit" (Sun and Li, 2018; Mamba and Ali, 2022). Therefore, the agricultural export trade of G20 countries significantly contributes to the growth of agricultural TFP. The study finds that the impact of agricultural trade on agricultural TFP is positive and significant, however the effect of import and export trade is different.

To eliminate the effect of multicollinearity, this section uses the decentered agricultural trade volume and institutional environment to generate interaction terms as a way to test the moderating effect of institutional environment on the relationship between agricultural trade and agricultural TFP growth. If the interaction term is significant, then the moderating effect of institutional environment is significant. If not, then institutional environment does not play a moderating role on agricultural trade and agricultural TFP. If the coefficients of the interaction term are in the same direction as the coefficients of the core explanatory variables, it means that the institutional environment can strengthen the role of agricultural trade in agricultural TFP growth. However, if the coefficients of the two are in opposite directions, it means that the institutional environment weakly promotes the role of agricultural trade in agricultural TFP.

From the estimated results of the moderating effect of institutional environment in Table 8, decentered agricultural trade is significant at the 1% level and the interaction term between institutional environment and agricultural trade is significant at the 1% level with a coefficient of 0.184. Both the core explanatory variables and the interaction term are significant and both are significant in the same direction, indicating that the institutional environment reinforces the positive contribution of agricultural trade to agricultural TFP. The possible reason is that a good institutional environment not only means that a country has a higher economic level, but also has more comprehensive safeguards. Such as a higher level of trade facilitation, better international trade regulations, etc., which reduces the explicit and invisible costs of trade and makes agricultural trade activities more active. At the same time, a complete institutional environment is also conducive to capital accumulation and technological innovation, thus better exploiting the role of agricultural trade in agricultural TFP growth (Liu and Wang, 2017). Thus, hypothesis 2 is confirmed.

TABLE 8 Moderating effect of the institutional environment.

	(1)
	lntfp
lntrade	0.411***
	(3.92)
lntrade*inst	0.184***
	(2.83)
inst	0.111*
	(1.70)
Constant	3.652**
	(2.07)
Control variables	Yes
Time fixed effects	Yes
Individual fixed effects	Yes
R-squared	0.423
Observations	190

*, **, ***Indicate significant at 10, 5, and 1% significance level respectively, t-statistic in ().

7. Conclusions and policy recommendations

7.1. Conclusions

This paper takes G20 countries as its research subject and measures the agricultural total factor productivity (TFP) in G20 member countries from 2010 to 2019 using the DEA-Malmquist index method to explore the impact of agricultural trade on TFP. This study has the following main conclusions. First, agricultural trade in G20 countries positively and significantly contributed to agricultural TFP, indicating that agricultural trade in G20 countries positively added to the growth of their agricultural TFP. Among the control variables, foreign direct investment, human capital, irrigation infrastructure, and agricultural employment size are negatively significant and do not play a positive role in enhancing the growth of agricultural TFP. Two variables, urbanization and economic development levels respectively, are not significant, of which the urbanization level has a positive effect and the economic development level a negative effect. Second, agricultural export trade positively contributes to agricultural TFP growth from the heterogeneity of trade flows, while import trade is insignificant and the coefficient is negative. Combined with the theoretical basis, this may be due to the learning effect and economies of scale triggered in the process of agricultural exports that promote the growth of agricultural TFP, while import trade may lead to agriculture's high external dependence in G20 countries, thereby squeezing the development space of their domestic agriculture. In addition, the technology spillover carried by imports requires a certain foundation to be absorbed and utilized, hence the effect of import trade on agricultural TFP in this study. Therefore, the effect of import trade on agricultural TFP in this study is insignificant and negative. Third, the interaction term between the institutional environment and agricultural trade is positive and significant, indicating that the institutional environment strengthens the role of agricultural trade in promoting agricultural TFP growth. A good institutional environment not only helps to reduce the risk and uncertainty of agricultural trade and promote more dynamic trade activities, but also provides an effective guarantee for agricultural development, thus giving better play to the role of agricultural trade in promoting agricultural TFP.

7.2. Policy recommendations

Based on the theoretical and empirical findings, this study puts forward the following suggestions. First, there is a need to improve agricultural research investment and increase the promotion of agricultural technology. The government should not only formulate policies related to agricultural science and technology, but also supervise the implementation of such policies to ensure that agricultural research investment is used for agricultural innovation and research and development. In addition, it should also increase agricultural technology promotion, apply advanced production technologies to a wider range of agricultural production and, through technology introduction and absorption, accumulate capital factors faster and thereby accelerate the growth of agricultural TFP. Secondly, it is suggested to improve the trade cooperation mechanism and thus enhance trade facilitation. On the one hand, the G20, as a cooperation mechanism, should take practical measures to improve agricultural productivity, promote agricultural investment, and improve the trade environment through consultation to promote the sustainable development of global agriculture. On the other hand, countries should improve the level of trade facilitation according to the prevailing situation of their agricultural development, relax market access in a targeted manner, reduce non-tariff barriers, promote international trade in agricultural products, expand agricultural cooperation methods and fields, and the promote multi-level development of agricultural cooperation, thus furthering the improvement of agricultural TFP. Third, is the issue of cultivating advantageous agricultural products and improving the international competitiveness of agricultural products. Countries should increase the cultivation of their advantageous agricultural products, improve the quality of agricultural products by upgrading agricultural technology, and then improve the competitive advantages of agricultural products, promote the entry of advantageous agricultural products into the international market, expand their market share, and deal with the continuous expansion of the agricultural trade deficit and the problem of food security while giving better play to the role of export trade in improving domestic agricultural TFP. It is recommended to deepen the reform and build a high-quality institutional environment. A perfect institutional environment can lay a good foundation for the development of agricultural technology and agricultural trade, which is one of the important macroscopic influencing factors that can enhance the international competitiveness of agriculture. Countries should focus on the improvement of their institutional environment to create favorable conditions for agricultural trade and domestic agricultural development. The government should continuously deepen the reform of government institutions and build a high-efficiency and low-risk institutional environment conducive to improving the government's performance. At the same time, when improving the institutional environment, there is a need to focus on rationalizing the relationship between the government and the market, further stimulating market vitality, and encouraging agricultural enterprises to "go global" and enter the international market more deeply, which can help promote the circulation of production factors and thus promote the growth of agricultural TFP.

This study explores the impact of G20 countries' agricultural product trade on agricultural TFP while providing useful references for the agricultural development of these countries and makes suggestions for the high-quality development of China's agricultural economy. However, due to the influence of both subjective and objective factors, this study still has certain shortcomings that require further in-depth research. These include: (1) At present, scholars use different input and output factor indicators, including for measuring agricultural total factor productivity. After referring to most of the literature, this study selects an input-output combination which is more suitable for country research. However, there may be problems with incomplete calculation angles, so in future research a set of measurement methods that are closer to the actual situation and easy to use need to be designed. (2) The scope of this study encompasses G20 countries, with the main research objects being nine developed countries and 10 developing countries. There are relatively few types of data available, and some indicator data are missing or cannot be compared with the agricultural industry in one-to-one correspondence, which may lead to errors in empirical results. In future research, more reasonable variables can be found for analysis so as to obtain more reliable results. (3) This study only discusses the impact of agricultural product trade on agricultural TFP while deeper exploration of the mechanism of action has not been carried out in the empirical part, and the analysis has only been combined with theory. In future research processes, an in-depth study of the mechanisms impacting agricultural trade on agricultural TFP should be conducted on an empirical basis.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JX: empirical analysis, conception, model design, writing original draft, approve the final version to be published, and agree the accountable for all aspects of the work. YW: data processing. XZ: model design. SE: literature review. ZL: empirical test. HZ: data analysis, writing original draft, resources, data processing, approve the final version to be published, and agree the accountable for all aspects of the work.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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